

1. **Project Name:** Stress Assisted Corrosion in Boiler Tubes
2. **Lead Organization:** Institute of Paper Science and Technology  
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4. **Project Partners:**

Industrial Partner	Type of Participation	Points of Contact
<b>Babcock &amp; Wilcox</b>	In-kind labor	Mr. John Hainsworth
<b>Hercules Inc.</b>	In-kind labor, Boiler-tube failure database	Mr. Mel. Esmacher Mr. Norris Johnston
<b>International Paper</b>	In-kind Labor	Dr. Ray Vasudevan
<b>Longview Inspections</b>	Non-destructive Testing of tubes with SAC	Mr. Mike Cooper
<b>MeadWestvaco</b>	Boiler Tube samples for failure analysis, In-kind labor, Field testing	Dr. W. B. A. Sharp, and Mr. Steve Lukezich
<b>Ondeo-Nalco</b>	Boiler-tube failure database, In-kind labor	Mr. Paul Desch
<b>Weyerhaeuser</b>	Boiler Tube samples for failure analysis, In-kind labor, Field testing	Dr. Peter Gorog

5. **Date Project Initiated and FY of Effort:** Project started in March 2002
6. **Expected Completion Date:** September 2005
7. **Project Technical Milestones and Schedule:**

Task ID	Milestone	Planned Completion	Actual Completion	Comments
1.0	<b>Lab simulation of SAC</b>			
1.1	Establish autoclave operation	April 2003	Completed	Autoclave and heaters are working satisfactorily
1.2	Develop tensile test rig	August 2003		
1.3	Simulate SAC in lab tests	Sept. 2004		
1.4	Oxide growth experiments	Sept 2004		
2.0	<b>Material characterization</b>			
2.1	Examine tubes with SAC	Sept. 2003	In-progress	Various tubes were received and were examined at ORNL and IPST
2.2	Document inspection reports	Dec. 2003	In-progress	
2.3	Inspections to assess SAC rate	Sept. 2004		
3.0	<b>Evaluation of stress effects</b>			

3.1	Document failure reports	April 2003	In-progress	Some data was received and is being reviewed. Required information is missing in most cases
3.2	Deploy field strain gages	Dec. 2003		
3.3	Model internal stress/strains			
4.0	<b>Environmental effects</b>			
4.1	Assess key chemistry data	Mar. 2004		
4.2	Deploy on-line monitoring	April 2004		
4.3	Document effect of cleaning	Sept. 2003		
5.0	<b>Communication to US industry</b>			Presentations were made at TAPPI and NACE meetings and appropriate Committees attended by US industry reps.
5.1	Technical review meetings	Every six months	In-progress	Second meeting will be held in June 2003
5.2	Special topic workshops	Once a year		
5.3	Final report	Feb. 2005		

## 8. Past Project Milestones and Accomplishments:

- Main objective of this research is the development of a laboratory test that simulates SAC in industrial boilers.
  - A special autoclave with recirculation loop was designed and commissioned at IPST in FY03 to simulate the waterside conditions in industrial boilers. Sensors for monitoring and controlling the water chemistry have been tested.
  - First tests to develop magnetite film on the carbon steel surface will be conducted before June 2003.
- Comparison study was conducted at ORNL to evaluate capability and sensitivity of radiography and two types of ultrasonic inspection techniques to detect SAC in tubes removed from a recovery boiler.
  - In one technique, ultrasonic waves were introduced longitudinally on the cold side surface of the tube and reflection analysis (at the wave launch location or a remote location) was performed to identify potential circumferentially oriented flaws.
  - In a second technique, ultrasonic waves were introduced circumferentially from the process side of the tubes to locate longitudinally oriented flaws near attachment welds.
  - These tubes were further sectioned and cleaned. A number of tested tubes in this study showed significant (10-20 mils) SAC cracks which could not be detected by these NDT techniques.
- One task in FY 03 was to document SAC inspection reports and draw some conclusions on key parameters related to SAC.
  - Ondeo-Nalco shared a large database containing information on past boiler related failures from different chemical and manufacturing industries.
  - Although a large amount of data was collected but some of the key parameters, important for this project, like boiler operating parameters or chemistry upsets were not available in these databases.
  - Other industrial partners have offered to share similar data in FY 04 and we will continue to accumulate this information and when available, extract useful relations between key chemistry or metallurgical parameters and SAC susceptibility in industrial boilers.

- A number of failed boiler tubes were received at IPST as well as at ORNL from the industrial partners for failure analysis
  - A number of tubes were sectioned and mounted to reveal SAC cracks and microstructural features associated with crack initiation.

#### **9. Planned Future Milestones:**

- In FY 04 the main new task will be to identify factors influencing residual and operating stresses. This will involve the measurement and modeling of stresses associated with different types of attachment welds and studies of the yield strength of waterside scales.
  - Representative tubing sections with a variety of attachment welds will be used to collect residual stress measurements at ORNL.
  - A mathematical model will be developed at ORNL to estimate the corresponding stresses on the tube ID surface where waterside cracks form.
- As the second task we will characterize the materials parameters associated with SAC.
  - Representative tubing specimens, with and without oxide accumulations and crack indications, will be prepared for metallography at IPST and ORNL to compare weld quality, microstructure, hardness, and oxide composition profiles in/around crack indications with areas where no cracking was observed.
- In FY 04 we will continue tests in recirculation-loop autoclave at IPST to evaluate environmental effects (chemicals, pH, oxygen content on the initiation and propagation of SAC).
  - Results from the laboratory will be compared with boiler experiences through a critical analysis of field inspection data that will be supplied by industrial partners in the project.
- An important part of this project is to exchange of information with the U. S. companies for whom SAC is a significant issue.
  - Work from these studies will be presented to the industry through a colloquium next year as well as through presentations at various conferences including Corrosion-2004 at New Orleans, and TAPPI Engineering Conference.

#### **10. Issues/Barriers:**

We have not encountered any major technical barriers so-far in this project which will force us to deviate from our proposed path. However, ran into following issues while working on FY03 tasks:

- Inconsistent quality and incomplete historic data with inspection companies has limited our capability to extract or identification useful chemical or metallurgical trends related to SAC.
  - More companies are being contacted to collect further data with hope that we will get some appropriate field data. Inconsistent quality may be overcome or minimized in significance via a large quantity of data made available from participating industry team members.

- Accelerating factors for lab tests may negatively influence key factors being analyzed for the development of SAC in the laboratory.
  - Results of accelerated testing will be evaluated for metallographic similarities to boiler-SAC and a limited number of long term exposures (with accelerating factors reduced or eliminated) will also be completed for comparison with results of accelerated tests.

In spite of these issues, we do not anticipate any big deviations from our proposed tasks or budget for FY-04.

#### **11. Intended Market and Commercialization Plans/Progress:**

- Boiler tubes in various industries including petroleum, chemical, glass, pulp and paper, and metal industry have experienced stress assisted corrosion (SAC). In the pulp and paper industry, any water leak in the boiler can result in boiler explosion. Therefore, the intended market for the application of results from this project is very wide. Main goal of this project is to clarify the mechanism(s) of stress-assisted corrosion of boiler tubes for the purpose of determining key parameters in its mitigation and control.
- Main product of this research will be SAC mitigation strategies in terms of water chemistry control, identification and avoidance of susceptible metallurgical microstructures and better welding/design practices to minimize strains on tubes to avoid fracture of protective scale. It is anticipated that the results will yield increased operating efficiencies represented by decreased downtime (greater intervals between inspection and maintenance cycles) with associated energy and cost savings.
- Commercialization of key results from this project will be accomplished through the R&D partners and industry contributors, who will use SAC mitigation information generated through laboratory simulation results as well as field measurements.

#### **12. Patents, publications, presentations:**

- Presentation at Boiler water treatment subcommittee for the Recovery Boiler Committee at the TAPPI Engineering meeting at San Diego in 9<sup>th</sup> September, 2002.
- Presentation at TEG-163X meeting held during NACE 2003 Conference at San Diego, in late March. Representatives from water treatment companies, inspection companies as well as boiler owner representatives attended this meeting.
- Presentation and poster at OIT-IMF annual review meeting at Albuquerque, NM

## **Highlight**

During the last 15 years, US paper companies had to replace lower furnace tubes or decommission many recovery boilers due to stress-assisted corrosion (SAC) on the waterside of boiler tubes. In fact, more than half of the power and recovery boilers that have been inspected reveal SAC damage, which portends significant energy and economic impacts. SAC is indicated by crack-like fissures that initiate and propagate on the waterside of boiler tubes, typically near external attachment welds. Propagation of SAC (with or without concomitant external corrosion) can lead to de-rating of boilers and tube failures, possibly resulting in potential smelt-water explosions and extended downtime for maintenance or repairs.

The centerpiece of this research is the development of a laboratory test that simulates SAC in industrial boilers, and the control of key conditions of the test to establish the parameters that have the greatest effects on SAC initiation and propagation. The work will be divided into five tasks.

Task 1: simulate SAC in the laboratory for the purpose of testing current and new remediation strategies under a range of conditions applicable to all types of boilers and the variety of operating conditions encountered industrially.

Task 2: characterize material parameters associated with SAC. This will involve characterization of composition and structure of tube materials, attachment welds and waterside scales from industrial boilers with and without SAC, and will attempt to correlate rates of propagation of SAC to material and operating variables.

Task 3: identify key factors related to the influence of residual and operating stresses. This will involve the measurement and modeling of stresses associated with different types of attachment welds and studies of the yield strength of waterside scales.

Task 4: evaluate environmental effects (chemicals, pH, oxygen content, etc.) on the initiation and propagation of SAC, both with field measurements and in laboratory tests, and through a critical analysis of a large amount of field inspection data that will be supplied by industrial partners in the project.

Task 5: communicate the results of the research to US industry. The industrial partners will meet at least twice a year as a steering committee to provide direction to the researchers

In FY 2003 a special autoclave with recirculation loop was commissioned at IPST simulate the waterside conditions in industrial boilers. Sensors for monitoring a controlling the water chemistry have been tested. Comparison study was conducted at ORNL to evaluate capability and sensitivity of radiography and two types of ultrasonic inspection techniques to detect SAC in tubes removed from a recovery boiler. One task in FY 03 was to document SAC inspection reports and draw some conclusions on key parameters related to SAC. Odeco-Nalco shared a large database containing information on past boiler related failures from different chemical and manufacturing industries. Hercules Inc. has also offered to share similar database in FY04.